Asian Journal of Advances in Research

4(1): 265-286, 2021

SOIL FERTILITY AND MICRONUTRIENT STATUS IN TISSUES OF MAIZE IN DARO LABU DISTRICT, WEST HARARGHE ZONE, EASTERN ETHIOPIA

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AUTHORS' CONTRIBUTIONS

This work was carried out in collaboration among all authors. All authors read and approved the final manuscript.

Received: 10 February 2021
Accepted: 17 April 2021
Published: 21 April 2021

Original Research Article

ABSTRACT

Depletion of soil fertility due to soil erosion and nutrient mining farming system leads to decline soil productivity and crop yields. The study was initiated to assess soil fertility status and to determine micronutrient concentration in the tissues of maize grown at Daro Labu district, Eastern Ethiopia. A field survey was conducted to collect general information. A total of 12 composite soil samples from the depth of 0-20 cm and 12 maize tissue samples were collected from the district. Data were analyzed by using SPSS version 20. The soil texture was sandy clay loam. Soil bulk density was varied from 1.3 to 1.4 g cm^{-3}. The total porosity of soil was very high with a value ranged from 41.5 to 45.3%. The soil pH (6.3 - 6.8) were varied from slightly acidic to a neutral level. The soil was very low in OC content with values ranged from (0.5 to 0.9%). The TN content of the soil was low which was varied from 0.04 to 0.22%. The soils available P content ranging from 10.08 to 16.2 $mgkg^{-1}$. The CEC of soil was ranged from medium to high. The concentrations of exchangeable Ca and Mg were found to be sufficient in soil of the study area. Exchangeable K was high to very high. The soil had an adequate level of DTPA extractable Fe and Mn whereas deficiency of Cu and B in the soil. The soil showed a deficiency of Zn in 25% of the soil sample. Maize tissue had sufficient concentration of Fe and Mn. However, 41.67%, 41.67% and 75% of maize tissues were deficient in Cu, Zn, and B respectively. The extractable Fe, Mn, Cu, Zn, and B concentrations in a plant tissue were positively correlated with their respective soil micronutrients. The study result indicates that OM, total N, Cu, Zn and B are the limiting factors for crop production. The use of integrated soil fertility management practices with increasing organic matter addition should be implemented. Thus, fertilizers containing N, Cu, Zn, and B need to be applied by conducting further experiments under green house and field conditions by considering soil type and crop variety could be recommended.

Keywords: Chemical properties; micronutrients; maize; physical properties; soil fertility.

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1. INTRODUCTION

Soil fertility is one of the primary constraints affecting agricultural production in Sub-Saharan Africa [1,2]. Increasing population pressure in the region has contributed to this constraint by reducing the size of land holdings and fallow periods. This is particularly in the areas where population densities are high, such as in the highlands of East Africa. The scenario with regard to soil fertility and land productivity in Ethiopia is similar to other neighboring eastern and central African countries that have high annual rates of nutrient depletion (i.e. > 40 kg N ha^{-1} and > 30 kg K_2O ha^{-1}) [3].

Ethiopia faces a wider set of soil fertility issues beyond chemical fertilizer use, which has historically been the major focus for extension workers, researchers, policymakers, and donors. If left unchecked, this wider set of soil fertility issues will limit future output and growth in agriculture across the country. It has also been identified that the three primary biophysical limitations, among others, which decrease agricultural production in Ethiopia are poor soil health, low soil fertility, and crop nutrient imbalances [4]. In some areas, these biophysical factors already limited the effectiveness of chemical fertilizer in increasing agricultural productivity. Poor soil health in terms of chemical, physical, and biological qualities due to loss of organic matter, macro and micronutrient depletion, topsoil erosion, acidity, salinity, and deterioration of other physical properties are among the major causes of soil fertility depletion in Ethiopia [4].

Maize (*Zea mays* L.) is a viable food grain for millions of people who live in marginal areas of Africa, South Asia and Central America [5]. In Ethiopia, maize is the second important crop after teff (*Eragrostis tef*) in terms of total area production. Maize production accounts for about 27.43% of the 87.48% of annual cereal production in Ethiopia [6]. In the Oromia region, where the study area was located, about 4.67 million ton of maize grain were produced during the 2018 main cropping season on around 1.1 million hectare's and 7 hundred thousand hectares [6]. The average grain yield in the Oromia region is about 4000.78 kg ha^{-1} below the industrialized world [6]. A whole range of growth reducing factors is responsible for this low grain yield. The inherent low soil fertility is highly affecting crop production. These soils are not rich in organic matter. In addition, little or no litter is added back to the soil due to the complete removal of crop residues since it is used as forage for animals. Thus, repeated cultivation and harvest result in depletion of nutrients and organic matter (OM).

Depletion of soil fertility leads to declining crop yields and a rise in the number of food-insecure people [7]. Compared to other causes of soil fertility depletion; soil erosion and nutrient mining can be easily reversed through soil conservation practices and the addition of organic and inorganic fertilizers. Nonetheless, in Ethiopia where 50 – 80% of the animal manure and 70 – 90% of the crop residues are removed from the farm and/or used for fuel, soil fertility is seriously declining and needs intervention to reverse.

Soil macronutrient survey conducted by Murphy [8] indicates that nitrogen (N) and phosphorus (P) were found to be deficient in many parts of the country. Subsequent fertilizer demonstration studies conducted by FAO through Freedom from Hunger Campaign also revealed that while crops responded to Diammonium Phosphate (DAP) and Urea in many locations, their response to potash fertilizer was inconsistent. Therefore, a recommendation was made to use the two fertilizers (DAP and Urea) across the country for crop production. As a result, the application of these fertilizers began in the late 1960s [9]. Thus, in order to increase crop yields, the government of Ethiopia has launched an extension package that gives more attention to high external inputs and high yielding varieties [10]. The national recommended application rate is 100 kg of DAP and 50 kg Urea per hectare [10]. However, the real experience shows that farmers are applying only smaller amounts of mineral fertilizer between 7 and 10 kg ha^{-1} annually [10]. In contrast to N and P containing fertilizer applications, micronutrient has not been applied to the soil, because since then little or attention has not been given to micronutrients thus leading to unbalanced fertilization and poor nutrient management and crop quality [11].

Continuous application of macronutrients such as N and P fertilizers has a significant contribution towards soil micronutrients depletion. For example, approximately two to six times more of the micronutrients are being removed annually from the soil than are applied to it in soils of India [12]. This is significant in Ethiopia, where there is no micronutrient application to the soil in the form of inorganic fertilizers or organic fertilizers [13]. In addition to this, the availability of micronutrient to plant growth is highly dependent on some soil factors such as parent materials, organic matter content, adsorptive surface, soil pH, lime content, soil texture, topography, and nutrient interactions in the soil [14,15]. Most research findings confirmed that certain soil micronutrients were deficient in the soil of Ethiopia which limits crop productivity. The deficiencies of Mo, Cu, and Zn are mainly reported on

Ethiopian Nitisols [16]. Also, Yifru and Mesifn [17] reported the deficiency of Fe and Zn in the majority of soil samples collected from the Vertisols of the central Ethiopia. Ashenafi et al. [18] reported the deficiency of Fe, Zn and Mn in the soils of central rift valley of Ethiopia. Furthermore, the deficiency of B is reported in the soils of East Wollega and Wolaita zone [19,20]. Therefore, to reverse the deficiency of micronutrients, it's important to apply the fertilizers containing those micronutrients.

Currently, more attention is being given to fertilizing the soil with micronutrients in many Sub-Saharan countries including Ethiopia. Ethiopian Soil Information System (EthioSIS) of Agricultural Transformation Agency (ATA) and Ministry of Agriculture (MoA) is currently pursuing complete soil fertility assessment to come up with solid, evidence-based and targeted fertilizer recommendations and other management interventions for agricultural land soils [21]. Although there were many different studies in the country, those former soil fertility investigations were fragmented and had no soil test-based fertilizer recommendation approach at the country level.

The assessments of micronutrients were conducted at a large scale throughout the country with limited soil samples and the absence of plant tissue analysis for micronutrients. Levels of micronutrients in plant tissue should be monitored to determine the effectiveness of the management strategies and changes in their availability. Soil tests are commonly used to assess the sufficiency or deficiency of essential plant nutrients. Although soil tests provide information about a soil's ability to supply plant-available nutrients, it is an indirect measurement. Plant analysis, on the other hand, reveals the nutritional status of the plant directly and when combined with the soil tests can be used to evaluate the nutritional sufficiency of the soil–plant system and further to design corrective intervention measures [22].

According to diagnosis results of soil analysis of some micronutrients status by ATA [21], boron is highly deficient and to some extent, Zn and Fe are potentially limiting nutrient for crop production in Daro labu district. However, the overall soil fertility and micronutrient status of major crops and area-specific soil micronutrient analysis has not been studied in Daro labu district. In addition, periodic assessment of important soil properties and their responses to changes in land management is necessary in order to improve and maintain the fertility and productivity of soils [23]. Micronutrient concentration in soil and its availability can be affected by soil physical and chemical properties and correlated to each other. However, soil fertility status and its relation to micronutrient content have not been studied and no information in connection with this for the study areas. Therefore, this study was initiated with the objectives: To assess the soil fertility status of maize growing fields and to determine micronutrient concentration in the tissues of maize grown in the study area.

2. MATERIALS AND METHODS

2.1 Description of the Study Areas

2.1.1 Location

The study was conducted in Daro Labu district, West Hararghe Zone of Oromia National Regional State. Daro Labu district is located at 434 km east of Addis Ababa and about 115 km from Chiro; the capital town of the zone. The district is located between 08º 19'15'' and 08°42' 55'' North and 40º10'00'' to 40º50'00" East and the altitude of the study area ranges between 1350 and 2450 meters above sea level (m.a.s.l.) The district is bounded by Hawi Gudina district in the south, Arsi zone in the west, Guba Koricha district in the North West, Habro district in the north and Boke district in the East.

2.2 Climate and Soil

Data obtained from the meteorology station located at Mechara Agricultural Research Center indicates that the mean annual (2010-2018) rainfall of the area is about 1094 mm. The study area is characterized by a bimodal rainfall pattern of distribution. The short rainy season usually starts in March and extends to May, while the main/long rainy season stretches from the end of June to September. The ambient temperature of the district varies from 14 to 26^{o}C with an average of 20^{o}C. The major soil type of the study area is Nitisols and its textural class is sandy clay loam which is reddish in color.

2.3 Farming System

The agricultural activities and livelihood in the district are characterized by the presence of a subsistence mixed farming system of both crop and livestock production. The major cereal crops grown are sorghum (*Sorghum bicolor*), and maize (*Zea mays*). Khat (*Catha Edulis*) and coffee (*Coffea*) are the main cash crops grown in the study area. Some vegetable crops, such as potato (*Solanum tuberosum*), tomato (*Lycopersicon esculentum*), cabbage (*Brassica oleracea*) and onion (*Allium cepa L.*) are grown in the dry season using irrigation where surface water is available. The irrigation water source is dominantly river water which flows throughout the year. The main livestock in the area is cattle, donkeys, sheep, goats, and poultry. Livestock are used as a source of food (meat, milk, and milk products), while manure is used for soil fertility improvement. Sales of milk and milk products, and livestock are also a major source of cash for farmers of the study area.

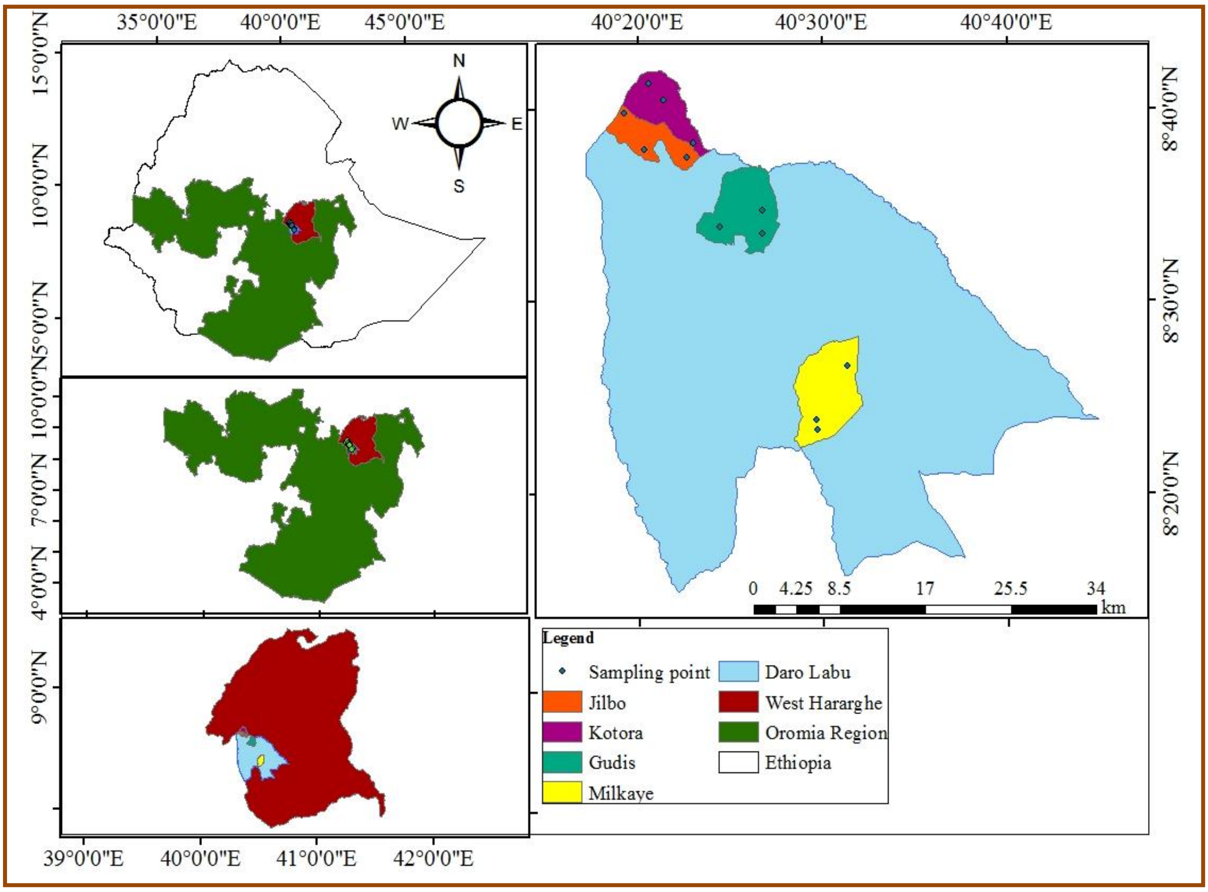

Fig. 1. Map of the study area

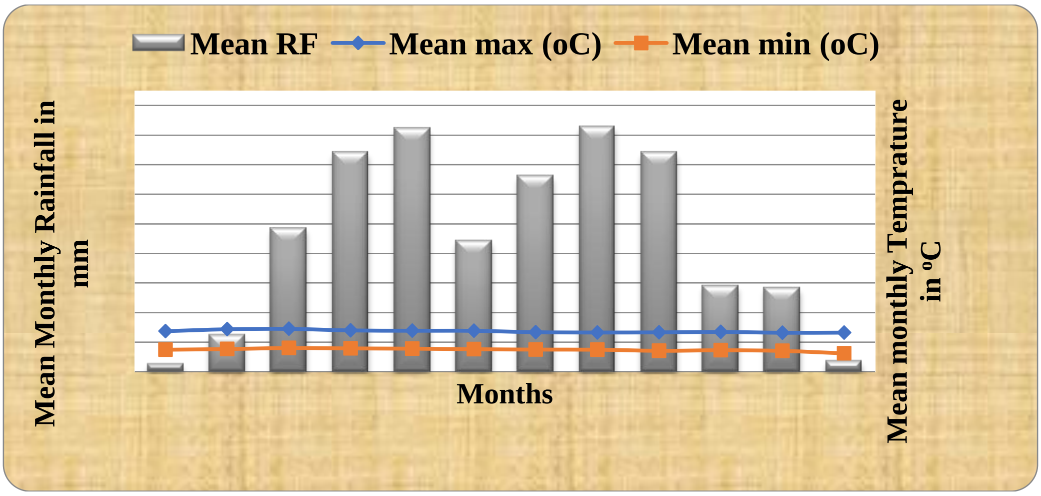

Fig. 2. Mean monthly rainfall (RF), maximum and minimum temperatures of the study area from 2010-2018 (Mechara Agricultural Research Center Meteorological station)

2.4 Site Selection, Soil and Plant Tissue Sample Collection

The study was carried out during the 2018 cropping season. Four kebeles out of twenty-nine kebeles were selected from the district. The selection of kebeles was based on the potential of maize production area. Accordingly, three maize fields were selected based on the willingness of the farmers from each kebeles (small administrative unit), for a total of 12 sampling sites.

A preliminary survey and field observation were carried out in order to get general information about the landforms and land uses, topography, slope gradients, longitude, latitude, and soil fertility management practices of the selected farmers` fields. During preliminary survey and field observation, data of spatial information (altitude, latitude and longitude) was recorded using Garmin GPS 72 while slope gradient was measured using clinometers. In addition, crop residue management, type and amount of fertilizers used, and dominant previous crop for each plot were recorded (Table 1).

Based on the initial data collection one site in each field was selected for sampling using the 'circle' method. Both soil and tissue samples were collected within a 15 m radius of the center.

Soil sample were collected to a depth of (0-20 cm) depending on the effective root depth of most annual crops. Each composite sample consisted of 20 subsamples within a 15 m radius from a selected point using the circle method. Totally, 240 subsamples to make 12 composite soil samples were collected based on the complexity of topography and variability of the soil. Similarly, a core sampler was used to collect an undisturbed soil samples for bulk density determination. Soil samples were not collected from restricted areas such as animal dung accumulation places, poorly drained and any other places that cannot give representative soil samples. The composite soil samples were prepared from thoroughly mixed auger sub samples. After mixing approximately 1 kg of the composite samples with proper labeling on each sampling bag and samples were transported to the laboratory for analysis.

The maize ear leaves are best indicators of mineral nutrients [24]. Therefore, maize at the initial silking stage, from the ear leaf was collected. Twelve complete individual maize leaves were taken at random within the sampling circle. To make 12 tissue samples, 240 maize tissue sub samples were collected.

Table 1. Physiographic characteristics and soil fertility management practices of the study area

Kebeles	Altitude m.a.s.l	Slope (%)	Previous crop	Residue mgt	Fertilizer used (kg ha^{-1})		ton ha^{-}1
					NPS	Urea	FYM
Milkaye	1659	2	Maize	Cleared	25	15	0.55
Gudis	1668	3	Maize	Cleared	20	5	0.25
Kotora	1714	6	Sorghum	Cleared	50	25	0.25
Jilbo	1721	9	Maize	Cleared	25	25	0.35

Where; Mgt = management, FYM = Farm yard manure, m.a.s.l = meter above sea level

Table 2. Soil physical and chemical analysis method

Physical properties	Methods of analysis	Source
Texture	Hydrometer	Bouyoucos [26]
BD	Core	Blake [27]
PD	Pycnometer	Blake [27]
Chemical Properties		
pH(H_2O)	pH meter	Van Reeuwijk [28]
SOC	Wet oxidation	Walkley and Black [29]
TN	Kjeldahl	Blake [27]
Available P	Olsen	Olsen et al. [30]
CEC	Titration	Sahlemedhin and Taye [31]
Exchangeable Ca and Mg	AAS	Rowell [32]
Exchangeable K and Na	Flame photometer	Rowell [32]
Extractable Fe, Mn, Zn and Cu	DTPA	Okalebo et al. [33]
Fe, Mn, Zn and Cu in plant tissue	DTPA	Okalebo et al. [33]
Extractable B	Hot Water Soluble Boron	Bingham [34]
B in plant tissue	Hot Water Soluble Boron	Bingham [34]

2.5 Soil and Plant Tissue Sample Preparation and Analysis

Soil samples collected from the field were air-dried, crushed and passed through a 2 mm sieve after careful removal of plant parts and other unwanted materials for some soil physical and chemical analysis. Soil samples were ground to the size of 0.5mm sieve for TN and SOM analysis.

Plant leaves were first washed with distilled water, oven-dried at 70°C for 48 hours to a constant weight, ground, passed through 2mm sieve and placed in paper bags [25]. The oven-dried ground plant tissue sample was ashed in a muffle furnace at 550°C for 6 hrs for Fe, Mn, Cu, Zn, and B analysis.

2.6 Statistical Analysis

Data analysis was carried out by using Statistical Package for Social Sciences (SPSS) software version 20. The mean soil analytical results were interpreted as very low, low, medium, high, and very high using standard ratings. Simple correlation analysis was carried out to reveal the magnitude and directions of relationships among soil physicochemical properties and also between soil properties and micronutrient concentration in plant tissue.

3. RESULTS AND DISCUSSION

3.1 Soil Physical Properties

3.1.1 Soil texture

The soil in the study areas varied substantially in their particle size distribution. The soil particle size distributions of maize growing fields were ranged from (52 to 67%) for sand, (15 to 24%) for silt and (18 to 25%) for clay (Table 3). Particularly, the lowest mean values of sand (53.67%) and the highest mean values of silt (22.67%) and clay (23.67%) was recorded at Milkaye, while the highest mean values of sand (65.67%) and the lowest mean values of silt (15.33%) and clay (19%) was recorded at Gudis site.

According to the USDA soil texture classification system described by Rowell [32], two soil textural classes, sandy clay loam, and sandy loam were identified. About 75 and 25% of maize growing fields are found to be sandy clay loam and sandy loam, respectively. In general, sand-size fraction followed by clay fraction dominated the study area.

The most probable reasons for the slight variation in their particle size distribution might be due to differences in slope gradient and, elevation (Table 1). Consistent with this suggestion, Thangasamy et al. [35] reported that variation in soil texture may be caused by variation in topography and translocation of clay. From this study, it was found that soils at lower elevation and slope gradient have higher clay content than soil at a higher elevation and slope gradient. In agreement with this finding, Sitanggang et al. [36] reported that soil textural variations are mainly associated with variation in topography.

In general, the textural classes of soils in almost all the study area under natural conditions have good drainage. A potential disadvantage is that as the sand content increases water holding capacity decreases, which might make successful rain-fed agriculture difficult particularly under erratic rainfall conditions.

3.2 Bulk, Particle Densities and Total Porosity

Soil bulk density affects root activity, water and air movement and overall growth of crops. The mean values of soil bulk density varied among fields. The soil bulk density values ranged from 1.33 to 1.42 g cm^{-3} (Table 3). Comparatively, the highest (1.4 g cm^{-3}) and the lowest (1.35 g cm^{-3}) mean bulk density values were recorded at Gudis and Milkaye sites, respectively.

The variation in bulk density could be attributed to variation in soil organic matter content and intensity of cultivation [37]. Accordingly, the highest bulk density value of soil at the Gudis site could be attributed to relatively lower organic matter content and a high sand fraction of the soil. The soils with relatively high OM content have lower bulk density because of greater pore space associated with high OM and clay fraction. Thus, the present study indicates that as the organic matter content of the soil increases bulk density decreases. Pravin et al. [38] also reported similar results.

The soil bulk density of the study area at the depth of upper 20 cm was found to be an acceptable range for sandy loam and sandy clay loam which is less than 1.61 g cm^{-3} according to Amusan et al. [39]. Based on the critical level given by Hazelton and Murphy [40], the soil bulk density of the current study area was moderate and indicates that the soils of the study area were not too compacted. This indicates the existence of loose soil conditions and hence, good structure. Similarly, Landon [41] confirmed that, soil bulk density values within the ranges reported in this study are an ideal for proper root development.

Similar to bulk density, the mean values of soil particle density varied among fields. The particle density value was ranged from 2.41 to 2.49 g cm^{-3} (Table 3). Relatively, the highest (2.48 g cm^{-3}) and the lowest (2.43 g cm^{-3}) mean values of particle density were recorded at Gudis site.

Table 3. Mean values of some soil physical properties of maize growing fields in Daro Labu district

Site	Descriptive Statistics	Sand (%)	Silt (%)	Clay (%)	Soil texture	BD (g cm^{-3})	PD (g cm^{-3})	TP (%)
Milkaye	Mean	53.67±1.53	22.67±1.53	23.67±1.53	SCL	1.35±0.02	2.43±0.02	44.58±0.61
	Range	52 – 55	21 - 24	22 - 25		1.33 - 1.37	2.41 – 2.45	44.08 – 45.27
Gudis	Mean	65.67±1.15	15.33±0.58	19.00±1.00	SL	1.40±0.03	2.48±0.02	43.55±0.69
	Range	65 - 67	15 - 16	18 – 20		1.37 – 1.42	2.46 – 2.49	42.97 – 44.31
Kotora	Mean	58.67±6.43	19±3.46	22.33±3.06	SCL	1.38±0.02	2.46±0.04	43.67±1.88
	Range	54 - 66	15 – 21	19 – 25		1.37 – 1.41	2.41 – 2.48	41.49 – 44.76
Jilbo	Mean	57.33±1.53	22±1.00	20.67±0.58	SCL	1.37±0.01	2.44±0.02	43.78±0.32
	Range	56 - 59	21 – 23	20 – 21		1.36 – 1.38	2.42 – 2.45	43.44 – 44.08
	Mean	58.83	19.75	21.42		1.38	2.45	43.89
Total	SD	5.41	3.47	2.39	SCL	0.03	0.03	1.00
	Range	52 - 67	15 - 24	18 – 25		1.33 – 1.42	2.41 – 2.49	41.49 – 45.27
	Median	56.50	21	21.00		1.37	2.45	44.08
	CV (%)	9.19	17.57	11.16		2.17	1.22	2.28

Mean ± SD, BD = Bulk density, PD = Particle density, TP = Total porosity, SD = Standard deviation, CV = Coefficient of variation, SCL = Sandy clay loam, SL = Sandy loam

Table 4. Mean values of soil chemical properties of maize growing fields in Daro Labu

Site	Descriptive statistics	pH (H_2O)	OC (%)	TN (%)	C: N	Avail. P (mg kg^{-1})
Milkaye	Mean	6.74±0.04	0.74±0.13	0.16±0.05	4.63±0.85	14.21±1.44
	Range	6.70 – 6.77	0.60 – 0.85	0.13 – 0.22	3.80 – 5.50	13.22 – 15.87
Gudis	Mean	6.44±0.06	0.55±0.04	0.07±0.02	7.86±1.56	10.80±0.67
	Range	6.40 – 6.50	0.50 – 0.58	0.06 – 0.10	5.91 – 8.96	10.08 – 11.40
Kotora	Mean	6.62±0.08	0.66±0.04	0.09±0.05	7.33±4.35	14.82±1.22
	Range	6.53 – 6.69	0.62 – 0.69	0.04 – 0.13	4.48 – 12.41	13.88 – 16.20
Jilbo	Mean	6.34±0.01	0.69±0.01	0.11±0.01	6.27±0.40	13.00±1.54
	Range	6.33 – 6.34	0.68 – 0.69	0.10 – 0.11	6.21- 6.89	11.74 – 14.71
Total	Mean	6.53	0.66	0.11	6.00	13.21
	SD	0.17	0.10	0.05	2.35	1.93
	Range	6.33 – 6.77	0.50 – 0.85	0.04 – 0.22	3.80 – 12.41	10.08 – 16.20
	Median	6.52	0.68	0.11	6.06	13.39
	CV%	2.60	15.15	45.45	35.93	14.61

Mean ± SD, pH= power of hydrogen, OM = Organic matter, TN = Total nitrogen, C: N = Carbon to nitrogen ratio, Avail.P = Available phosphorus, SD = Standard deviation, CV = Coefficient of variation

The most probable reasons for the slight variation in their soil particle density might be due to differences in OM content and heavy minerals in the soil. Therefore, the lowest mean values of particle density recorded at the Milkaye site might be attributed to relatively the higher organic matter content of the soil. Similarly, the variation in particle density could be attributed to the organic matter content of soil [42]. The presence of the relatively high amount of iron which indicates the presence of heavy minerals like iron oxide (Table 6) might have contributed to higher particle density. This is in agreement with the finding of Achalu et al. [43] report indicates that increase in the mean value of particle density with increase in an iron oxide and heavy minerals in the soil. In general, the observed mean values of soil particle density in the study area were lower than the average value of the mineral soils worldwide, which is considered to be about 2.65 g cm^{-3} [44].

Total porosity of the soils was varied with bulk and particle density. Soil total porosity ranged from 41.49 to 45.27% (Table 3). Particularly, the highest (44.58%) and the lowest (43.55%) mean values of total porosity were recorded at Milkaye and Gudis sites, respectively.

According to the FAO [45] rating, the percent total porosity of the soil in the study areas was rated as very high > 40%. This implies that there is better aggregation that can create conducive soil physical conditions concerning total soil porosity for crop production in the study area. Total porosity increases as the bulk density decreases while it decreases as bulk density increases. The higher values of total porosity corresponded to relatively the higher amount of organic matter contents and lower bulk density values. Therefore, relatively the higher percent of total porosity at the Milkaye site could be attributed to relatively higher organic matter contents and lower bulk density of soil. The lower value of percent total porosity at the Gudis site corresponds to relatively higher bulk density and lower soil organic matter contents. This is in line with results reported by Mohammed [46] for soils of Jelo sub-catchment in the Chercher highlands, while Wakene [47] reported that the low total porosity was the indicator of the low organic matter content of the soil.

3.3 Soil Chemical Properties

3.3.1 Soil reaction (pH)

The pH of the soil in water varied considerably among studied sites. The soil pH of the study area was extended from 6.33 to 6.77 (Table 4). Relatively, the highest (6.74) and the lowest (6.34) mean pH values were recorded at Milkaye and Jilbo sites, respectively.

The variation in soil pH means values among fields might be due to differences in slope gradients, elevation, loss of basic cations, application of acid-forming fertilizers, and prevailing weather conditions (Table 1). Therefore, relatively the recorded lower mean pH values at the Jilbo site might be attributed to a higher slope gradient that could result in a reduction of basic cations due to topsoil erosion and leaching and also application of nitrogen-containing fertilizer (NPS and Urea) used for crop production (Table 1). Besides, H^+ ion released by nitrification of NH_4^+ sourced chemical fertilizers and roots of crops to soil solution with low OM contents on the surface layer of cultivated land there by reducing soil pH. In agreement with this finding Mohammed et al. [48] reported that soils in higher altitudes and slopes had lower pH values, probably suggesting washing out of soil basic cations. Similarly, Ahmed [49] reported that continuous cultivation practices, high rainfall and steepness of topography could be some of the factors responsible for the reduction of soil pH at the middle and upper elevations. Similar research results are also reported by Cardelli et al. [50] and Alexandra et al. [51] who stated that soil pH values were significantly lower on the surface layer for cultivated soils when compared to non-cultivated soils due to the application of NH_4^+ sourced fertilizers to cultivated lands that nitrifies NH_4^+ and the uptake of basic cations by crops. In contrast, comparatively, the highest pH values at the Milkaye site might be associated with limited removal of basic cations by erosion due to gentle slope gradients and high OM content of the soil. Besides, the presence of higher pH might be accredited to the effect of relatively high content of OM that forms Al and Fe-OM complexes and release of hydroxyl ions as well as deposition of basic cations [52].

Regardless of the differences observed in soil pH among the fields, the pH values recorded in the study areas are within the range that are quoted as suitable for production of many crops. A result reported here represents pH values that are ideal for availability of most of the essential nutrients and for proper functioning of most beneficial soil microorganisms. According to Gazey and Davies [53], the soil pH value between 5.5 and 8.0 was considered as ideal for plant growth. Thus, the availability of most of the plant nutrients might not be significantly limited within the observed soil pH ranges at the study area.

3.3.2 Soil organic carbon, total nitrogen and C: N ratio

There was a spatial variation of OC in the study area. Across the fields, the values of soil OC content of maize growing fields were ranged from 0.50 to 0.85% (Table 4). Relatively the highest (0.74%) and the lowest (0.55%) mean values of OC were recorded at Milkaye and Gudis sites respectively. According to the rating suggested by Tekalign [54], the soil organic carbon content of the study area can be categorized under very low to low.

The most probable source of variation in soil OC contents among the fields might be due to variation in altitude, topography, cropping system, FYM application (Table 1). Also, OC variability between farms might be attributable to different soil management practices between farms and fields over time. Furthermore, the level of soil OC was high for fields of flat with no or low soil erosion history as they could receive OC from upper slope areas via processes of erosion deposition. On the other hand, fields of steep slopes with severe soil erosion could contribute to lower OC contents as the OC depletes through the removal of the surface soils. Similarly, Musefa [55] reported that high level of SOC recorded at a lower slope due to OC accumulation. Since the nutrient concentration is related to OM, Tittonell et al. [56] found that nutrient variability between farms might be attributable to variation of soil management practices between farms and fields over time. In addition to this, the highest organic carbon content recorded at the Milkaye site might be due to relatively gentle slope gradient where the soil moisture storage is better which in turn lowers soil temperature resulted in comparably better biomass production, thus contribute to higher OC content of the soil. This result is in agreement with the work of Abebe and Endalkachew [57] in Nitisol of Southwestern Ethiopia and Usmael [58] in the soil of Haramaya district, East Hararghe zone.

The mean values of OC contents of soil in the study areas ranged from very low to low which need improvements. Due to shortage of land, intensive cultivation is expected without fallowing thus, aggravate rapid oxidation of the small amount of organic carbon returned to soils of the cultivated lands. Total removal of crop residues due to a number of competing ends such as animal feed, fuel, construction and sell to others to generate income are common practices in the study areas. In consent with the findings of this study, Wakene and Heluf [23] and Alemayehu and Sheleme [59] demonstrated that intensive cultivation results in rapid oxidation of soil OC. Moreover, the total removal of crop residues for animal feed and a source of energy was reported as being among the main reasons for low OC content in soils of Ethiopia [60]. Yihenew [61] also confirmed that most cultivated soils of Ethiopia are generally poor in OC content.

For coarse textured-soils, the addition of organic materials would help in improving soil aggregates and hence water retention capacity. The soils in Daro labu are all below 1.0% SOM and would be improved with an increase in SOM. Thus, soils of the study area are urgently needing application of organic fertilizers (via farmyard manure, compost or vermicompost) and surface soil management.

The total nitrogen concentration of the soil in the study area differed among farms. The soil total nitrogen content of maize fields was ranged from 0.04 to 0.22% (Table 5). Relatively, the highest (0.16%) and the lowest (0.07%) mean percentages of total nitrogen were registered at Milkaye and Gudis sites respectively.

According to the rating suggested by Tekalign [54], soils were found to be low in their TN except for the soil at the Milkaye site which was found to be moderate. The total N content of the soils in the study area was followed a similar trend with the OM content of the soil. These facts indicate that the source of total N and its ultimate source of variation is soil organic matter contents. This suggestion is consistent with that of Murage et al. [62] who reported that soil organic matter is a surrogate for soil total nitrogen content. Similarly, about 95% of the total nitrogen comes from soil organic matter [41].

Comparatively, the highest TN content of soils was recorded at the Milkaye site could be attributed to relatively high OM content and gentle slope gradients which contribute to minimize leaching and volatilization of nitrogen by reducing soil temperature. On the other hand, relatively the lowest soil TN content was recorded at the Gudis site could be attributed to relatively low OM content, steep slope gradient and high percentage of sand fraction which exacerbate loss of TN. In agreement with this finding, Mesfin Abebe [63] reported that, one of the characteristic features of tropical environment is its high temperature which leads to rapid loss of TN due to volatilization. Soil erosion due to steep slopes and heavy rainfall as well as leaching, may have contributed to nitrogen loss. Certainly, it is one of the most deficient elements in the tropics for crop production.

The results are also supported by Zhihui et al. [64] who stated that FYM application increased the OM content of the soil. In general, the mean values of soil TN in the study areas were low due to the factors mentioned above. Since maize is cereal crops, cereal-based continuous cropping that often returns limited organic source to the soil whereby the continuous cultivation exacerbates the rapid decomposition of this low amount of OM input into the soil system. Lower external N inputs (like plant residues and animal manures) and N (nitrate ions) leaching problem as a result of higher rainfall during summer also contribute to lower total N content in soils of the study area. This finding is in agreement with the research finding of Solomon et al. [65] who reported a low level of total N in soils of cultivated land. The findings of the study, therefore, clearly indicate that nitrogen-containing fertilizers, mineral or organic sources, should be applied to soils for sustainable crop production.

Carbon to nitrogen ratio (C: N) is an index of nutrient mineralization and immobilization whereby a lower C: N ration indicates higher rate of mineralization and a higher C: N ration indicates higher rates of immobilization [44]. The soil Carbon to nitrogen ratio of the study area was ranged from 3.80 to 12.41 (Table 4). Relatively, the highest (7.86) and the lowest (4.63) mean values of C: N ratio was recorded at Gudis and Milkaye site respectively.

According to C: N ration rating suggested by Landon [41], the C: N ration of soils of the study area was categorized as very low (<8). In effect, the lower the value, the higher is the proportion of N in organic matter (i.e. high-quality organic matter) and the more the accumulation of NH_4^+ which stimulates more mineralization. Soils with high values of C: N ratios have an organic matter with relatively high lignin and other hard substances that are resistant to decomposition [66]. The slight variation in C: N values among fields could be a result of variation in the intensity of cultivation and soil management practices, micro-climate, and quality of organic material applied to the soil. In line with this, Saikh et al. [67] reported that cultivation of land results in reduction of soil organic matter and total N, and increase soil C: N ratio as in the case of soil at Gudis site.

3.4 Available Phosphorus

The soil available P content was found to be variable among the studied fields. Across the maize fields, the soil available P ranged from 10.08 to 16.2 mg kg^{-1} (Table 4). Comparatively, the highest (14.82 mg kg^{-1}) and the lowest (10.8 mg kg^{-1}) mean values of Olsen extractable P were registered at Kotora and Gudis sites respectively.

Based on the rating suggested by Cottenie [68], the available P contents of soil in the study area found to be medium (10-17 mg kg^{-1}). The variability in soil available P content might be the result of different soil management practices, specifically, type and rate of organic and inorganic fertilizers used in cultivated land and slope gradient (Table 1), which can cause downward movement of P with runoff water from top slope and accumulated at the bottom slope among farms. Besides these factors, variation in parent material, soil texture and soil pH might be contributed for the differences in available P among fields.

The highest available P at Kotora site could be due to relatively high amount of P containing fertilizer (NPS) application. These results are in agreement with the report of Wakene [47] and Gebeyaw [69] who indicated that available P in cultivated land was higher due to mineral P fertilization resulted in the building up of plant-available P on top soils compared to non-fertilized plots. Furthermore, Bhat et al. [70] estimated that only 20% of applied P fertilizer is taken up by crops in the year of application and the remainder is fixed in soils in various degrees of availability to the succeeding crops.

In contrast, the lowest available P at Gudis site is attributable to the sandy nature of this soil combined with the inherent characteristics of the parent material. In addition to this, relatively lower pH of this field could be the other causes of lower available P content of soil. The results of this study are in agreement with the findings of Sanchez et al. [71] that P is limiting nutrient in many sandy soils of the semi-arid tropics and in acid, weathered soils of the sub humid and humid tropics.

Even if the figures are different, the soil available P content of the study areas are medium. Lower organic matter content of these cultivated fields but medium available P content indicates the application of P containing fertilizers. However, OM is not necessarily the primary supplying source of available P in highly weathered tropical soils rather mineral weathering has considerable importance as a source of soil P [72]. This finding is in agreement with the findings reported by Gebeyaw [69] and Kedir et al. [73].

However, contrary to this finding, low level of available P was recorded in the surface layers of the cultivated land in the Chercher highlands [48]. Wakene and Heluf [23] also reported that low content of available P is most common in Ethiopian soil. The present study showed that, available P is medium due to application of P containing fertilizers.

3.5 Cation Exchange Capacity (CEC)

The analyzed result showed that the soil CEC of the study area showed variation among studied fields. The soil CEC was ranged from 24.20 to 29.20 Cmol $_{(+)}$ kg^{-1} (Table 5). Relatively the highest (28.47 Cmol (+) kg^{-1}) and the lowest (24.73 Cmol (+) kg^{-1}) mean values of CEC were recorded at Milkaye and Gudis sites respectively.

Based on the rating suggested by Hazelton and Murphy [40], the soils of the study area varied from medium (12-25 Cmol (+) kg^{-1}) to high (25-40 Cmol (+) kg^{-1}) in their CEC. Accordingly, the recorded mean values of soil CEC at Milkaye, Kotora and Jilbo sites were categorized to high, whereas at Gudis site were categorized as medium. The variation in CEC values of the studied soils is attributable to variation in soil organic matter content and percentage of clay fraction. Basically, CEC is determined by the relative percentage of the two main colloidal substances; humus and clay. As the amount of OM in the soil increases, the total negative charge in the soil increased which in turn increase the CEC of the soil [44]. In addition, soils containing high clay contents have high cation exchange capacity. Therefore, the highest value of CEC was probably due to the possible contribution of organic matter content and clay particles [74].

Thus,the higher soil CEC values of soil at Milkaye site might be attributed to the increase in clay contents and OM which result an increase in the exchange sites of the soil which is in agreement with the findings of Ahmed [49]. Arifin et al. [75] also found that negative charge derived from the clay minerals increases the CEC of soils. Thus, higher CEC values might be imply that the soils have high buffering capacity against induced change. Therefore, soil CEC could be improved through application of OM.

In contrast, the lower CEC recorded at the Gudis site might be due to relatively low OM contents and high percentage of the sand fraction which have low surface areas for the exchange site. In line with this, Usmael. [58] reported that, low clay content and high sand fraction lowers CEC of soils. In general, the overall mean values of the soil CEC for soil of the study area were categorized to high. The variation among crop fields might be due to management practices, soil particle size distribution and soil OM content.

3.6 Exchangeable Basic Cations and Percent Base Saturation

The soil exchangeable basic cations of the study areas showed variability among farms. Comparatively, the highest mean values of exchangeable Ca (18.39 Cmol (+) kg^{-1}), Mg (2.78 Cmol (+) kg^{-1}), K (1.33 Cmol (+) kg^{-1}) and Na (0.51 Cmol (+) kg^{-1}) were recorded at Milkaye site, where as the lowest mean values of exchangeable Ca (14.30 Cmol (+) kg^{-1}), Mg (1.91 Cmol (+) kg^{-1}), and Na (0.36 Cmol (+) kg^{-1}) were registered at Gudis and exchangeable K (0.69 Cmol (+) kg^{-1}) were recorded at Kotora site (Table 5).

The order of exchangeable basic cations in most agricultural soil is generally Ca > Mg > K > Na with a pH of 5.5 or more. The finding of this study also shows similar order of cations in agreement with the report of Usmael. [58]; Kedir et al. [73] and Musefa [55]. The binding cation is stronger, since the higher the charges of ions (charge density) i.e. trivalent cations are more strongly bound than divalent cations, which in turn are more tightly held than monovalent cations on the colloidal surfaces. Exchangeable Ca and Mg, therefore, were by far higher than exchangeable K and Na on exchange site in the study areas. Since divalent cations (shorter radii) were higher than monovalent which were similar to the report of Adesodun et al. [76]. Similarly, Foth [77] elucidated that, as a result of small energy of adsorption of K and Na, it is more likely to exist in soil solution than colloidal sites and be removed from soil by leaching.

According to the ratings set by FAO [78], the exchangeable Ca and Mg were categorized as high and medium respectively. The exchangeable K was categorized as high to very high status. The exchangeable Na was grouped as medium status.

The variations in exchangeable basic cation content among farms could be due to variation in OM content, amount of clay, parent materials, slope gradient, elevation and soil management practices (Tables 1 & 4). Comparatively, the highest soil exchangeable bases (Ca, Mg, K and Na) recorded at Milkaye could probably be relatively higher clay content, OM, gentle slope and lower elevation. The possible reason for the higher concentrations of exchangeable bases due to relatively higher OM is that, soil OM is the storehouse of nutrients and makes soil less susceptible to erosion which could prevent the loss of basic cations through leaching [79]. In addition to this, the exchangeable bases increased at the lower elevation (Milkaye site) of the study area. This might be because of removal of exchangeable basic cations by erosion from higher topography and their subsequent accumulation in the lower elevations. The result is similar with the report of Usmael [58] and Kedir et al. [73].

In contrast, lower exchangeable bases at Gudis site might be attributed to higher slope gradients, low OM contents and high percentage of sand particles which contribute to accelerate leaching of basic cations. Similarly, Achalu et al. [43] reported that, lower concentrations of exchangeable Ca, Mg, K and Na contents recorded in soils of cultivated land could be attributed to low OM content and leaching of basic cations from top soils of cultivated land.

Table 5. Mean values of exchangeable cations, CEC and PBS for soil of Maize growing fields in Daro Labu district

Site	Descriptive Statistics	(Cmol(+)/kg soil)					PBS %
		CEC	Ex. Ca	Ex. Mg	Ex. K	Ex. Na	
Milkaye	Mean	28.47±0.70	18.39±0.79	2.78±0.63	1.33±0.13	0.51±0.03	80.82±3.22
	Range	27.8 - 29.20	17.51 - 19.05	2.35 - 3.51	1.22 - 1.47	0.49 - 0.54	77.57 - 87.01
Gudis	Mean	24.73±0.5	14.30±0.78	1.91±0.08	1 ±0.25	0.36±0.06	71.05±3.06
	Range	24.20-25.20	13.61-15.15	1.84-2.00	0.71-1.16	0.30-0.42	68.02-74.13
Kotora	Mean	25.73±1.72	15.54±2.78	2.13±0.49	0.69±0.21	0.41±0.08	72.95±9.48
	Range	24.20-27.60	12.61-18.15	1.57-2.51	0.46-0.86	0.32-0.47	61.82-79.65
Jilbo	Mean	26.73±0.92	16.27±0.77	2.60±0.40	1.08±0.08	0.40±0.03	76.13±1.46
	Range	26.20-27.80	15.70-17.15	2.15-2.92	1.01-1.16	0.37-0.44	74.86-77.69
Total	Mean	26.42	16.13	2.36	1.03	0.42	75.47
	SD	1.70	2.03	0.53	0.28	0.07	5.98
	Range	24.20-29.20	12.61-19.05	1.57-3.51	0.46-1.47	0.30-0.54	61.82-84.01
	Median	26.20	15.92	2.33	1.09	0.43	75.99
	CV%	6.43	12.59	22.46	27.18	16.67	7.92

Mean ± SD, CEC = Cation exchange capacity, Ex = Exchangeable, PBS = Percent base saturation, SD = Standard deviation, CV = Coefficient of variation

From the fertility point of view, exchangeable Ca, Mg and K are not limiting nutrients to crop production. The results were in agreements with the common belief that Ethiopian soils are rich in potassium [8].

The soil PBS of the study areas showed variability among studied soil. Relatively, the highest (80.82%) and the lowest (71.05%) mean values of PBS were recorded at the Milkaye and Gudis sites respectively (Table 5). According to the ratings set by Hazelton and Murphy [40], the PBS of soil of the study areas were found to be High (60-80%), except the soil at Milkaye site which was found to be very high (>80).

The variation in PBS could be related to OM, soil texture, leaching, slope gradient, elevation and soil management practices. The highest PBS of soil at Milkaye site could be attributed to relatively high OM content, high percentage of clay fraction, gentle slope and lower elevation which retain basic cations against leaching. Similar finding was reported by Getachew and Heluf, [80]. In general, soils with high PBS are considered relatively more fertile because many of the bases that contribute to higher PBS are essential macro plant nutrients [72]. Accordingly, the soils of the study area had high to very high and considered fertile soils with regards to exchangeable cations especially Ca and Mg.

3.7 Extractable Micronutrients (Fe, Mn, Cu, Zn and B)

The values of DTPA extractable micronutrients in the soils were ranged for Fe (6.59 to 16.12 mg kg^{-1}), Mn (7.71 to 14.46 mg kg^{-1}), Cu (0.59 to 1.81 mg kg^{-1}), Zn (0.27 to 2.75 mg kg^{-1}) and hot water soluble extractable B (0.13 to 0.23 mg kg^{-1}). Particularly, the highest mean values of DTPA extractable Fe (14.59 mg kg^{-1}), Cu (1.79 mg kg^{-1}), and Zn (2.61 mg kg^{-1}) were recorded at the Jilbo site while Mn (13.73 mg kg^{-1}) and B (0.21 mg kg^{-1}) were recorded at Kotora and Milkaye sites respectively. On the other hand, the lowest mean value of extractable Fe (7.10 mg kg^{-1}) was recorded at the Milkaye site while Mn (8.27 mg kg^{-1}), Cu (0.69 mg kg^{-1}), Zn (0.35 mg kg^{-1}) and B (0.15 mg kg^{-1}) were recorded at the Gudis site (Table 6).

According to the rating described by Jones [81], 100% soil of the study areas was categorized as high and medium in their DTPA extracted Fe and Mn contents respectively. Therefore, the soil of the study areas had adequate levels of extractable Fe and Mn. On the other hand, 100% of soil was categorized as low and very low level in their extractable Cu and hot water-soluble B according to the rating suggested by Karltun et al. [82]. Although, the extractable Zn content of the soil is low at Gudis, medium at Milkaye and high at Kotora and Jilbo site. Thus 100% of soils of the study areas were deficient in their extractable Cu and B. On the other hand, 25% soil of the study areas was deficient in their extractable Zn contents. In agreement with this finding, ATA [21] reported deficiency of Boron and zinc in the study area.

The extractable micronutrient content of soils is influenced by many factors. According to Anil et al. [83], soil factors that affect the contents of soil micronutrients are organic matter, sand and clay fraction and soil pH. Accordingly, the availability of micronutrients increased with OM and clay contents in the study area. OM may promote the availability of such nutrients by supplying soluble chelating agents or organic acids that interfere with their fixation. The availability of micronutrients increased with the increase of OM also reported by Habtamu et al. [84]. They suggested that the higher available micronutrient recorded might be due to high OM concentrations that acted as a chelating effect and source of such micronutrients. The solubility and availability of most micronutrients are enhanced by acidic soil reaction [72]. Thus, relatively high concentrations of extractable micronutrients in the study areas are the reflection of the soil reaction (pH), which was in the range of slightly acidic. In addition to this, the availability of extractable Fe content of soil is inhibited by the presence of phosphorus and manganese due to antagonism of nutrients in a soil. Similarly, Iron availability decreased with the presence of P and Mn in the growth medium [85].

In contrast, the low level of extractable micronutrients (Cu, Zn and B) could be attributed to low OM, high percentage of sand fraction and poor soil management in the study areas. Similarly, Wajahat et al. [86] reported that most sandy soils are acutely deficient in micronutrients compared to clay soils. The low OM content of the soil is contributed to lower extractable soil micronutrient [47].

3.8 Maize Tissue Micronutrient Concentration

There existed variability of micronutrient concentration of maize tissue among fields. The micro nutrient concentrations of maize tissue were ranged for Fe (57.40 to 86.00 mg kg^{-1}), Mn (40.30 to 65.67 mg kg^{-1}), Cu (1.75 to 14.04 mg kg^{-1}), Zn (15.69 to 25.10 mg kg^{-1}) and B (0.36 to 6.68 mg kg^{-1}). Comparatively, the highest mean values of Fe and Cu concentration in maize tissue were recorded at the Jilbo site, while Mn, Zn and B were recorded at the Milkaye sites. On the other hand, the lowest mean values of maize tissue concentration of Fe, Mn, Cu, Zn and B were recorded at Gudis site (Table 7).

Table 6. Mean values of selected micronutrients for soil of maize growing fields in Daro Labu district

Site	Descriptive statistics	mg kg-1				
		Fe	**Mn**	**Cu**	**Zn**	**B**
Milkaye	Mean	7.10±0.53	13.01±0.64	0.82±0.02	0.68±0.10	0.21±0.02
	Range	6.59-7.65	12.53-13.73	0.81-0.84	0.58-0.79	0.19-0.23
Gudis	Mean	10.24±1.54	8.27±0.61	0.69±0.08	0.35±0.07	0.15±0.01
	Range	8.59-11.65	7.71-8.92	0.59-0.74	0.27-0.39	0.13-0.16
Kotora	Mean	12.86±2.63	13.73±0.64	1.09±0.25	2.23±0.3	0.19±0.03
	Range	11.06-15.88	13.25-14.46	0.81-1.25	1.99-2.57	0.16-0.22
Jilbo	Mean	14.59±2.16	13.4±1	1.79±0.02	2.61±0.12	0.2±0.02
	Range	12.12-16.12	12.29-14.22	1.77-1.81	2.52-2.75	0.18-0.22
Total	Mean	11.20	12.11	1.10	1.47	0.19
	SD	3.36	2.41	0.46	1.02	0.03
	Range	6.59-16.12	7.71-14.46	0.59-1.81	0.27-2.75	0.13-0.23
	Median	11.35	13.01	0.83	1.39	0.19
	CV%	30	19.90	41.82	69.39	15.79

Mean ± SD, SD = Standard deviation, CV = Coefficient of variation

Table 7. Mean values of micronutrient concentration of maize tissue in Daro Labu district

Site	Descriptive statistics	mg kg^{-1}				
		Fe	**Mn**	**Cu**	**Zn**	**B**
Milkaye	Mean	67.73±1.03	61.69±2.28	5.26±1.75	22.75±2.35	5.6±0.96
	Range	66.60 – 68.60	59.70 – 64.18	3.51 – 7.02	20.39 – 25.10	4.87 – 6.68
Gudis	Mean	63.93±6.31	51.74±9.94	2.05±0.51	16.47±0.78	0.6±0.28
	Range	57.40 – 70.00	40.30 – 58.21	1.75 – 2.63	15.69 – 17.25	0.36 – 0.90
Kotora	Mean	72.33±1.6	56.22±2.28	7.6±3.65	20.92±1.2	3.19±2.11
	Range	70.80 – 74.00	53.73 – 58.21	3.51 – 10.53	19.61 – 21.96	0.90 – 5.05
Jilbo	Mean	82.20±6.24	60.2±4.8	12.87±1.01	20.92±1.63	3.73±1.68
	Range	75.00 – 86.00	56.72 – 65.67	12.28 – 14.04	19.61 – 22.75	1.81 – 4.87
Total	Mean	71.55	57.46	6.94	20.26	3.28
	SD	8.12	6.35	4.50	2.77	2.23
	Range	57.40 – 86.00	40.30 – 65.67	1.75 – 14.04	15.69 – 25.10	0.36 – 6.68
	Median	70.40	58.21	6.14	20.39	4.06
	CV%	11.35	11.05	64.84	13.67	67.99

Mean ± SD, SD = Standard deviation, CV = Coefficient of variation

Table 8. Pearson correlation matrix for the relationship between selected soil characteristics, soil and maize micronutrients in Daro Labu district

	Soil										Maize tissue				
	pH	**OM**	**Sand**	**clay**	**CEC**	**B**	**Fe**	**Mn**	**Cu**	**Zn**	**B**	**Fe**	**Mn**	**Cu**	**Zn**
pH	1	.406	-.310	.043	.402	.318	-.666*	.314	-.564	-.350	.409	-.380	.092	-.351	.545
OM		1	-.813**	.714**	.605*	.905**	-.096	.748**	.340	.315	.590*	.310	.349	.287	.822**
Sand			1	-.938**	-.860**	-.928**	.042	-.765**	-.444	-.338	-.833**	-.328	-.389	-.236	-.723**
clay				1	.816**	.867**	.093	.723**	.621*	.435	.783**	.487	.463	.402	.593*
CEC					1	.785**	-.370	.573	.219	.034	.751**	.153	.325	.063	.603*
BS						1	-.047	.861**	.491	.432	.673*	.483	.281	.350	.825**
FeS							1	.197	.734**	.778**	-.072	.445	-.006	.581*	-.162
MnS								1	.576	.710**	.624*	.627*	.341	.610*	.812**
CuS									1	.869**	.288	.812**	.247	.806**	.286
ZnS										1	.188	.787**	.210	.834**	.323
BM											1	.178	.553	.174	.685*
FeM												1	.204	.839**	.437
MnM													1	.423	.393
CuM														1	.395
ZnM															1

**, ** Correlation is significant at $p < 0.05$ and 0.01, respectively, S = soil, M = Maize*

According to the ratings suggested by Plank and Donohue [24], the concentration of Fe and Mn were found to be within a sufficiency range in tissues of maize. The sufficient concentrations of Fe and Mn were in agreement with their soil concentration. This could suggest that the existence of adequate amounts of these micronutrients for maize production and their present deficiency may not be expected in the study area. Wondwoson and Sheleme, [11] from the pot experiment reported that adequate amounts of Fe and Mn in maize plant grown under high levels of these micronutrients. However, 41.67%, 41.67% and 75% of maize tissues were deficient in Cu, Zn and B concentration respectively. In contrast to soil analysis results that have shown 100% soil Cu and B deficiency while 25% soil Zn deficiency, tissue analysis did not reflect similar trends on the deficiency. Similarly, Dibabe et al. [13] and Wondwoson and Sheleme, [11] reported in pot experiments conducted on maize grown under Cu and Zn deficient soils of Ethiopia indicated that, maize didn’t respond to Cu and Zn (plant height, dry matter yield and nutrient uptake). Fanuel et al. [20] also reported 100% of soil low in their Cu contents, but only 28% of maize leaf was showed deficiency level.

The present study thus indicated that, maize plant has ability to absorb the required quantity of those micronutrients from the soil within its growing season. In agreement with this finding, Havlin et al. [72] report indicates plants that have greater root mass and hair, increased micronutrient solubility due to root exudates, the influence of soil pH and more efficient transport of micronutrients from roots to shoots. Furthermore, acidification of the rhizosphere from the applied ammonium-sourced N fertilizers and other acidic reactions was reported to enhance the availability and uptake of Cu, B, Fe, Mn and Zn by roots [87].

3.9 Soil and Maize Tissue Micronutrient Relationships

In order to evaluate whether a particular nutrient in the maize and sorghum is generally in a similar trend with soil micronutrient status, a simple correlation analysis was performed. The results of soil and plant interaction for all investigated micronutrients were showed a positive correlation with their respective nutrients (Table 8). The correlation analysis revealed that, there were significantly ($p \leq 0.05$) positive correlations ($r = 0.673$) for B while, highly significant ($p \leq 0.01$) positive correlation ($r = 0.806$) for Cu in soil and maize tissues. On the other hand, maize tissue Fe, Mn and Zn didn’t show significant correlation with their respective soil micronutrient contents.

The presence of non significant correlation indicates that the uptake of micronutrients not only affected by soil nutrient contents. Micronutrient uptake might be affected by other soil properties such as pH, texture, OM, CEC and other nutrient interactions. Similarly, FAO [88] report indicates the nutrient concentration of plants affected by soil reaction, OM, CEC and texture.

Fe and Cu uptake of maize was negatively ($r = -0.380$ and $r = -0.351$ respectively) correlated to soil pH while B, Mn, Zn was positively ($r = 0.409$, $r = 0.092$, $r = 0.545$ respectively) correlated to soil reaction. On the other hand B, Fe, Mn, Cu and Zn concentration of maize tissue was positively correlated with OM, CEC and clay fraction of soil. However, only B and Zn maize tissue concentration was showed significant ($p \leq 0.05$) positive correlation with OM, clay and CEC of soils.

The correlation matrix further revealed that, the existence of negative correlation of maize tissue B ($r = -0.072$), Mn ($r = -0.006$) and Zn ($r = -0.162$) with soil Fe contents were observed. Similarly, Mandal et al. [89] reported that high concentrations of Fe in the soil solution have an antagonistic effect on Zn absorption. Furthermore, Chinnery and Harding [90] have reported antagonistic effects of Mn on the uptake of Fe and vice versa. Boron is sorbed to Fe oxides in soil and its availability is lowest at pH ranged from 6 to 9 [91]. Zn content of soil reduced B accumulation in plant tissue and toxicity on plants grown in soils containing adequate B [92,93]. Iron uptake is reported to be decreased with the presence of Cu and Mn in the growth medium [94]. Aref [95] also reported antagonism between Zn in the soil and leaf Mn content. The uptake of Mn has been reported to be inhibited by Zn in a soil [20].

4. SUMMARY AND CONCLUSION

Depletion of soil fertility leads to declining crop yields and rise in the number of food insecure people. Thus, in order to improve soil fertility and subsequently increase crop yields more attention has to given to external inputs to the soil. The correlation of soil fertility level and plant tissue micronutrient concentration have been suggested for better understanding of soil fertility and its relation to plant micronutrient contents. Hence, this study was initiated to assess the soil fertility status and micronutrient concentration in the tissues of maize grown in the study area.

A preliminary field survey was undertaken to collect the general information about soil fertility management practices (type and amount of fertilizers used), crops grown previous year and record the data regarding latitude, longitude and slope gradient during the main cropping season. Four kebeles were selected from the districts based on their potential on maize production.

The soils of maize growing fields are sandy clay loam textural classes. Regarding particle size distribution, sand size fraction followed by clay fraction dominated the study area. The bulk density of soil was found to be within the range that is acceptable for sandy clay loam soils. On the other hand total porosity of the study area might also indicate that the soils are porous enough for water movement and good aeration.

Soil reaction (pH) was ranged from slightly acidic to neutral. These are within the range of soil pH that is considered as optimum for production of many crops. Soils of the study areas were poor in their organic carbon content. Similar to SOC content, the total nitrogen content of the soils was generally in the low category. Cropping system (mono cropping) and soil management practices (complete removal of crop residue from cultivated fields) are the most probable factors to lowering soil OC and TN in the study area. The soil C: N ratio of fields was very low indicating very low OC as compared to the TN content in the studied soils. The status of available P is better in most of the soils of the study area.

CEC of the soils ranged from medium to high category. The soils were at normal condition in their exchangeable bases (Ca, Mg and K). The exchange complex is dominantly occupied by Ca followed by Mg. Therefore, exchangeable Ca, Mg and K are not limiting mineral elements to crop production in the study area.

The DTPA extractable Fe and Mn content of soils were high level. Therefore, the soil had adequate levels of extractable Fe and Mn. On the other hand, extractable Cu and B were categorized as low status and hence deficiency of those micronutrients. Furthermore, the extractable Zn content of soil was ranged from low to high level. This indicated that, the soil Zn status was spatially variable in the study areas.

Similar to soil analysis, micronutrient concentration in plant tissue showed variation among fields in the study area. Accordingly, the concentrations of Fe and Mn in maize were found to be within a sufficiency range. In line with this, the soil of the study areas had adequate levels of extractable Fe and Mn. However, the deficiency of Cu, B and Zn was observed in maize tissues. In general, the sufficiency of Fe and Mn as well as the deficiency of Cu, Zn and B partly reflected in both soil and plant tissues.

The present study indicated that, the uptake of micronutrients is affected by soil pH, OM, soil texture, CEC and antagonism (nutrient imbalance) effect of soil micronutrients. Accordingly, Fe and Cu uptake of maize was negatively affected by soil pH and sand fraction of soil. Mn, Zn and B uptake of maize was negatively affected by sand fraction and soil Fe contents. In contrast, the micronutrient concentration in maize tissue was positively correlated with soil OM, clay fraction and CEC.

In conclusion, the soils of the study area are desirable in physical soil properties and exchangeable bases as well as adequate level of extractable Fe and Mn content. However, poor chemical properties and deficiency of some extractable micronutrients are identified. Specifically, the soils have problems related to OM, TN, extractable Cu, Zn and hot water soluble B. In general, intensive cultivation, complete removal of crop residue and no or little input of organic and inorganic fertilizers are the factors for deterioration of soil fertility status in the study area. Since soil OM is the storehouse for nutrients, soil fertility management practices should focus on the restoration and increasing of OM. With regards to plant tissue analysis result, Maize had adequate level of Fe and Mn concentration in their tissues. However, Cu, Zn and B concentration is deficient in their tissues. Finally, it can be recommended that, the use of sustainable soil nutrient management practices with increased organic matter addition, practices of crop rotation, biomass incorporation, increasing crop diversity, maintaining soil cover and optimum use of integrated chemical and organic fertilizers in cultivated lands are needed to amend soil problems. In addition, there should be integrated soil conservation measures to reduce loss of soil. Furthermore, soil test should be complemented with plant tissue analysis. Therefore, based on soil and plant tissue analysis result, fertilizers containing Cu, Zn and B need to be applied by conducting further experiments under green house and field conditions by considering soil type and crop variety for realizing better production in the study area. Since plant tissue analysis is a good indicator of micronutrient status in a soil, the response of crop to micronutrients should be tested by considering plant tissue analysis. Moreover, the rating of soil and plant nutrient contents should be done by considering the local situation.

ACKNOWLEDGEMENTS

I am pleased to express my sincere gratitude to Mr. Habtamu Hailu and Mr. Gabayo Chala for their unlimited help during sample collection. I would like to acknowledge Oromia Agricultural Research Institute (OARI) for financial and material support for the successful completion of the study. Also, I would like to thank Haramaya University Soil Chemistry Laboratory staff members for their valid supports and continuous encouragement in many ways during Laboratory analysis.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

REFERENCES

1. Sanginga N, Woomer P. Integrated soil fertility management in Africa: Principle, Practices and development process. Nairobi: Tropical Soil Biology and Fertility Institute of the International Center for Tropical Agriculture; 2009.
2. Vanlauwe B, Bationo A, Chianu J, Giller KE, Merckx R, Mokwunye U, Ohiokpehai O, Pypers P, Tabo R, Shepherd K, Smaling EMA, Woomer PL. Integrated soil fertility management: Operational definition and consequences for implementation and dissemination. Outlook Agriculture. 2010;39: 17–24.
3. Esilaba O, Fasil Reda, Ransom JK, Wondimu Bayu, Gebremedhin Woldewahid, Beyenesh Zemichael. Integrated nutrient management strategies for soil fertility improvement and striga control in Northern Ethiopia. Africa Crop Science Journal. 2000;8:403-410.
4. Gete Zelleke, Getachew Agegnehu, Dejene Abera, Rashid S. Fertilizer and soil fertility potential in Ethiopia: Constraints and opportunities for enhancing the system; 2010.
5. AATF (African Agricultural Technology Foundation). Feasibility Study on Striga Control in Sorghum. Nairobi, African Agricultural Technology Foundation; 2011.
6. CSA (Central Statistics Authority). Agricultural Sample Survey 2017/2018. Report on Area and Production for Major Crops (Private Peasant Holdings, Meher Season). Statistical Bulletin No. 586. Addis Ababa, Ethiopia; 2018.
7. Chillot Yirga, Hassan RM. Social costs and incentives for optimal control of soil nutrient depletion in the Central Highlands of Ethiopia. Agricultural System. 2010;103:153-160.
8. Murphy HF. A report on the fertility status and other data on some soils of Ethiopia, Experiment Station Bulletin No. 44, College of Agriculture Haile Sellassie I University, Dire Dawa, Ethiopia. 1968;551.
9. Wassie Haile and Tekalign Mamo. The effect of potassium on the yields of potato and wheat grown on the acidic soils of Chencha and Hagere Selam in Southern Ethiopia. International Potash Institute. 2013;1662-2499.
10. Elias E. Farmers' perceptions of soil fertility change and management. ISD and SOS Sahel International (UK). EDM Printing Press. Addis Ababa, Ethiopia; 2002.
11. Wondoson Tena, Sheleme Beyene. Identification of growth limiting nutrient(s) in alfisols: Soil physico-chemical properties, nutrient concentrations and biomass yield of maize. American Journal of Plant Nutrition and Fertilization Technology. 2011;1:23-35.
12. Katyal JC, Randhawa NS. Micronutrients. FAO Fertilizer and Plant Nutrition Bulletin No. 7, Food and Agriculture Organization (FAO), Rome, Italy; 1983.
13. Dibabe Asgelil, Bekele Taye, Assen Yesuf. The status of micronutrient in nitisols, vertisols, cambisols and fluvisols in major maize, wheat, teff and citrus growing areas of ethiopia. proceedings of the workshop on status of micro nutrient, Addis Abeba, Ethiopia, December 27, Ethiopian Institute of Agriculural Research. 2007;28–39.
14. Nazif W, Perveen S, Saleem I. Status of micronutrients in soils of district Bhimber (Azad Jammu and Kashmir). Journal of Agricultural and Biological Science. 2006;1(2): 35-40.
15. Eyob Tilahun, Kibebew Kibret, Tekalign Mamo, Hailu Shiferaw. Assessment and mapping of some soil micronutrients status in agricultural land of Alicho-Woriro Woreda, Siltie Zone, Southern Ethiopia. American Journal of Plant Nutrition and Fertilization Technology. 2015;5:16-25.
16. Teklu Baissa, Suwanarit A, Osotsapar Y, Sarobol E. Status of Cu, Zn, B and Mo in agricultural soils of Western Ethiopia: Laboratory assessment. Journal of Natural Science. 2003;37:408-420.
17. Yifru Abera, Mesfin Kebede. Assessment on the status of some micronutrients in vertisols of the Central Highlands of Ethiopia. International Research Journal of Agricultural Science and Soil Science. 2013;3(5):169-173.
18. Ashenafi Worku, Bobe Bedadi, Muktar Mohammed. Assessment on the status of some micronutrients of salt affected soils in Amibara area, Central Rift Valley of Ethiopia. Academia Journal of Agricultural Research. 2016;4(8): 534-542.

19. Kidanu Motuma, Achalu Chimdi. Availability of boron, sulfur and zinc and status of other selected soil properties under acidic soils of different land use types: The Case of Wayu Tuka District, East Wollega Zone. American-Eurasian Journal of Agriculture and Environmental Science. 2018;18(1):17-22.
20. Fanuel Laekemariam, Kibebew Kibret, Tekalign Mamo, Heluf Gebrekidan. Soil–plant nutrient status and their relations in maize-growing fields of Wolaita Zone, Southern Ethiopia, Communications in Soil Science and Plant Analysis. 2016;47(11):1343-1356.
21. ATA. Status of soil resources in Ethiopia and priorities for sustainable management. GSP for Eastern and Southern Africa, March 25-27, 2013, Ethiopian Agricultural Transformation Agency (ATA), Nairobi, Kenya; 2013.
22. Gary WHA. Futuristic view of soil and plant analysis and nutrient recommendations. Communication Soil Science and Plant Analysis. 1998;29:11–4.
23. Wakene Negassa, Heluf Gebrekidan. Forms of phosphorus and status of available micronutrients under different land-use systems of Alfisols in Bako area of Ethiopia. Ethiopian Journal of Natural Resources. 2003;5(1):17-37.
24. Plank CO, Donohue SJ. Reference sufficiency ranges for plant analysis in the Southern Region of the United States. Southern Cooperative Series Bulletin. 2000;394:11–19.
25. Wolf BA. Comprehensive system of leaf analysis and its use for diagnosing crop nutrients status. Soil Science Plant Analysis. 1982;13:1035-1059.
26. Bouyoucos GJ. Hydrometer method improvement for making particle size analysis of soils. Agronomic Journal. 1962;54:179-186.
27. Blake CA. Methods of soil analysis. Part I, American Society of Agronomy. Madison, Wisconsin, USA. 1965;1572.
28. Van Reeuwijk LP. Procedures for soil analysis, 3rd Edition. International Soil Reference and Information Center (ISRIC), Wageningen, the Netherlands. 1992;34.
29. Walkley A, Black IA. An examination of the Degtjareff method for determining soil organic matter and a proposed modification of the chromic acid titration method. Soil Science. 1934;37:29-38.
30. Olsen SR, Cole CV, Watanabe FS, Dean LA. Estimation of available phosphorus in soil by extraction with sodium bicarbonate. USDA Circular. 1954;939:1-19.
31. Sahlemedhin Sertsu, Taye Bekele. Procedures for soil and plant analysis. National Soil Research Organization, Ethiopian Agricultural Research Organization, Addis Ababa. 2000; 110.
32. Rowell DL. Soil science: Methods and applications. Addison Wesley Longman Singapore Publishers (Pte) Ltd., England, UK. 1994;350.
33. Okalebo JR, Gathua KW, Womer PL. Laboratory methods of soil and plant analyses: A working manual. 2nd Edition. TSBF –CIAT and SACRED Africa, Nairobi, Kenya; 2002.
34. Bingham FT. Boron, methods of soil analysis, Part 2: Chemical and mineralogical properties. America Society of Agronomy, Madison, WI, USA. 1982;431–448.
35. Thangasamy A, Naidu MVS, Ramavatharam N, Raghava Reddy C. Characterization, classification and evaluation of soil resources in Sivagiri Microwatershed of Chittoor District in Andhra Pradesh for sustainable land use planning. Journal of Indian Society Soil Science. 2005;53:11–21.
36. Sitanggang M, Rao YS, Nayan Ahmed, Mahapatra SK. Characterization and classification of soils in Watershed Area of Shikohpur, Gurgaon District, Haryana. Journal of Indian Society Soil Science. 2006;54:106–110.
37. Sharma VK, Anil Kumar. Characterization and classification of the soil of upper Maul Khad catchment in wet temperate zone of Himachal Pradesh. Indian Journal of Agro Pedology. 2003;13:39-49.
38. Pravin R. Chaudhari, Dodha, V. Ahire, Vidya D. Ahire, Manab Chkravarty, Saroj Maity. Soil bulk density as related to soil texture, organic matter content and available total nutrients of coimbatore soil. International Journal of Scientific and Research Publications. 2013; 3(2):01-08.
39. Amusan AA, Shitu AK, Makinde WO, Orewole O. Assessment of changes in selected soil properties under different land use in Nigeria. Electronic Journal of Environmental, Agricultural and Food chemistry. 2001;8:03-023.
40. Hazelton P, Murphy B. Interpreting soil test results. What Do All the Numbers Mean? 2nd Edition. CSIRO Publishing; 2007.
41. Landon JR. Booker tropical soil manual: A Handbook for soil survey and agricultural land evaluation in the Tropics and Subtropics. Longman Scientific and Technical, Essex, New York. 1991;474.
42. Birhanu Iticha, Muktar Mohammed, Kibebew Kibret. Impact of deforestation and subsequent cultivation on soil fertility in Komto, Western Ethiopia. Journal of Soil Science and

Environmental Management. 2016;7(12):212-221.
43. Achalu Chimdi, Heluf Gebrekidan, Kibebew Kibret, Abi Tadesse. Status of selected physicochemical properties of soils under different land use systems of Western Oromia, Ethiopia. Journal of Biodiversity and Environmental Sciences. 2012;2(3):57-71.
44. Brady NC, Weil RR. The nature and properties of soils, 13th Edition. Prentice- Hall Inc., New Jersey, USA. 2002;960.
45. FAO (Food and Agriculture Organization). Guidelines for Soil Description. FAO, Rome, Italy; 2006b.
46. Mohammed Assen. Land suitability evaluation in the Jelo Catchment, Chercher Highlands, Ethiopia (Published doctoral dissertation) Doctoral thesis. University of Free State, Bloemfontein, South Africa; 2003.
47. Wakene Negassa. Assessment of important physicochemical properties of Dystric Udalf (Dystric Nitosols) under different management systems in Bako Area, Western Ethiopia MSc, thesis Alemaya University, Alemaya, Ethiopia; 2001.
48. Mohammed Assen, Le Roux PAL, Barker CH, Heluf Gebrekidan. Soils of Jelo Micro-catchment in the Chercher Highlands of Eastern Ethiopia: I. Morphological and Physico-chemical Properties. Ethiopian Journal of Natural Resources. 2005;7(1):55-81.
49. Ahmed Hussen. Assessment of spatial variability of some physcio-chemical properties of soils under different elevations and land use systems in the western slopes of Mount Chilalo, Arsi. (Unpublished MSc thesis), Alemaya University, Alemaya, Ethiopia; 2002.
50. Cardelli R, Marchini F, Saviozzi A. Soil organic matter characteristics, biochemical activity and antioxidant capacity in Mediter-ranean land use systems. Soil and Tillage Research. 2012;120:8-14.
51. Alexandra M, Charles R, Jeangros B, Sinaj S. Effect of organic fertilizers and reduced-tillage on soil properties, crop nitrogen response and crop yield. Soil and Tillage Research. 2013; 126:11 - 18.
52. Abreha Kidanemariam. Soil acidity characteri-zation and effects of liming and chemical fertilization on dry matter yield and nutrient uptake of wheat (*Triticum aestivum* L.) on soils of Tsegede District, Northern Ethiopia. PhD Dissertation, Haramaya University, Haramaya, Ethiopia; 2013.
53. Gazey C, Davies S. Soil acidity: A guide for WA Farmers and Consultants. Department of Agriculture and Food, Western Australia, Perth; 2009.
54. Tekalign Tadese. Soil, plant, water, fertilizer, animal manure and compost analysis. Working Document No. 13. International Livestock Research Center for Africa, Addis Ababa, Ethiopia; 1991.
55. Musefa Redi. Assessment of soil fertility status under striga hermonthica infested sorghum (*Sorghum bicolor* L. moench) fields at Pawe, Northwestern Ethiopia. MSc thesis. Haramaya University, Haramaya, Ethiopia; 2016.
56. Tittonell P, Muriuki AW, Klapwijk CJ, Shepherd KD, Coe R, Vanlauwe B. Soil heterogeneity and soil fertility gradients in smallholder farms of the East African Highlands. Soil Science Society of America Journal. 2012;77:525–538.
57. Abebe Nigussie, Endalkachew Kissi. Physicochemical characterization of nitisol in Southwestern Ethiopia and its fertilizer recommendation using NuMaSS. Global Advanced Research Journal of Agricultural Science. 2012;1(4):66-73.
58. Usmael Mohammed. Soil fertility assessment and mapping of Becheke Sub-Watershed in Haramaya District of East Hararghe Zone of Oromia Region, Ethiopia. MSc thesis. Haramaya University, Haramaya, Ethiopia; 2016.
59. Alemayehu Kiflu, Sheleme Beyene. Effect of different land use systems on selected soil properties in South Ethiopia. Journal of Soil Science and Environmental Management. 2013;4(5):100-107.
60. Sheleme Beyene. Characterization of soils along a toposequence in Gununo Area, Southern Ethiopia. Journal of Science and Development. 2011;1(1):31-41.
61. Yihenew Gebreselassie. Selected chemical and physical characteristics of soils of Adet Research Centre and Its Testing Sites in Northwestern Ethiopia. Ethiopian Journal of Natural Resources. 2002;4(2):199-215.
62. Murage EW, Karanja NK, Smithson PC, Woomer PL. Diagnostic indicators of soil quality in product and non-productive smallholders' fields of Kenya's Central Highlands. Agriculture Ecosystem and Environment. 2000;79:1-8.
63. Mesfin Abebe. Nature and management of Ethiopian Soils. Alemaya University of Agriculture, Ethiopia. 1998;272.
64. Zhihui Y, Singh BR, Hansen S. Aggregate associated carbon, nitrogen and sulfur and their ratios in long-term fertilized soils. Soil and Tillage Research. 2007;95:161–171.

65. Solomon Dawit, Lhmann J, Tekalign Mamo, Fritzsche F, Zech W. Phosphorus forms and dynamics as influenced by land use changes in the Ethiopian Highlands. Geoderma. 2002;102: 41–59.
66. Olowolafe EA. An evaluation of soil fertility indicators using soil survey data on the Jos Plateau, Nigeria. Journal of Environmental Sciences. 2004;8(2):54-61.
67. Saikh H, Varadachari C, Ghosh K. Changes in Carbon, Nitrogen and Phosphorus Levels due to Deforestation and Cultivation. A Case Study in Simplipal National Park, India. Indian Journal of Soil Science. 1998;198:137-145.
68. Cottenie A. Soil and plant testing as a basis of fertilizer recommendations. FAO Soil Bulletin 38/2. Food and Agriculture Organization of the United Nations, Rome, Italy; 1980.
69. Gebeyaw Tilahun. Soil fertility status as influenced by different land uses in maybar areas of South Wello Zone, North Ethiopia. M.Sc. Thesis Submitted to School of Graduate Studies, Alemaya University, Ethiopia; 2007.
70. Bhat JA, Mandal B, Hazra GC. Basic slag as a liming material to ameliorate soil acidity in alfisols of Sub-Tropical India. American-Eurasian Journal of Agriculture and Environmental Science. 2007;2:321-327.
71. Sanchez PA, Sheperd KD, Soul MJ, Place FM, Buresh RJ, Izac AMN, Mokwunye AU, Kwesiga FR, Ndirtu CG, Woomer PL. Soil fertility replenishment in Africa. An Investment in Natural Resource Capital. Pp. 146. In: Buresh, R.J. Sanchez, P.A. and Calnoun, F. (eds.). Soil Science Society of America, No.51.SSSA. Am. Soc. Argon. Madison, Wisconsin, USA. 1997;1-46.
72. Havlin JL, Beaton JD, Tisdale SL, Nelson WL. Soil fertility and fertilizers: An introduction to nutrient management, 7th edition. New Jersey, USA: Prentice Hall; 2009.
73. Kedir Abate, Muktar Mohammed, Kibebew Kibret. Soil fertility assessment and mapping of spatial variability at Amareganda-Abajarso Sub Watershed, North-Eastern Ethiopia. East African Journal of Sciences. 2016;10 (1):1-14.
74. Abayneh Esayas. Some physico-chemical characteristics of the Raya Valley report. Ethiopian Journal of Natural Resources. 2001;3(2):179-193.
75. Arifin A, Tanaka S, Jusop S, Majid NM, Ibrahim Z. Assessment on soil fertility status and growth performance of planted dipterocarp species in Perak, Peninsular Malaysia. Journal of Applied Science. 2008;8:3795-3805.
76. Adesodun JK, Adeyemi EF, Oyegoke CO. Distribution of nutrient elements within water stable aggregates of two tropical agro ecological soils under different land uses. Soil and Tillage Research. 2007;92:190-197.
77. Foth HD. Fundamentals of soil science. 8th Edition. John Wiley and Sons, Inc. New York, USA; 1990.
78. FAO (Food and Agriculture Organization). Scaling Soil Nutrient Balances. Fertilizer and Plant Nutrition, Bulletin No. 15. FAO, Rome, Italy; 2006a.
79. Fageria N. The use of nutrients in crop plants. CRC Press, Boca Raton. Buol SW, Southard RJ, Grahm RC, Daniel PA, 2003. Soil Genesis and Classification 5th edition. Iowa State University Press. Ames, USA. 2009;550-555.
80. Getachew Fisseha, Heluf Gebrekidan. Characterization and fertility status of the soils of Ayehu Research Substation, Northwestern Highlands of Ethiopia. East African Journal of Sciences. 2007;1(2):160-169.
81. Jones JB. Plant mineral nutrition. In: Agronomic handbook: management of crops, soils and their fertility, CRC Pres, Boca Raton, FL, U.S.A. 2003;325.
82. Karltun E, Mamo T, Bekele T, Gameda S, Kidanu S. Ethiopian soil information system towards improved fertilizer recommendations in Ethiopia. Nutrient indices for categorization of fertilizer blends from EthioSIS District soil inventory data discussion paper; 2013.
83. Anil K, Anil KC, Vijay P, Vinod KS, Ummed S. Soil factors associated with micronutrient acquisition in crops- Biofortification Perspective; 2016.
84. Habtamu Admas, Heluf Gebrekidan, Bobe Bedadi, Enyew Adgo. Fertility status of soils under different land uses at Wujiraba Watershed, North-Western Highlands of Ethiopia. Agriculture, Forestry and Fisheries. 2014;3(5):410-419.
85. Follett RH, Murphy LS, Donahue RL. Fertilizers and soil amendments. Englewood Cliffs, New Jersey: Prentice-Hall; 1981.
86. Wajahat N, Sajida P, Iftikhar S. Status of micronutrients in soils of District Bhimber (Azad Jammu And Kashmir). Journal of Agricultural and Biological Science. 2006;1(2): 35-40.
87. Akhter N. Comparison of DRIS and critical level approach for evaluating nutrition status of Wheat in District Hyderabad, Pakistan. PhD dissertation, Faculty of Agriculture, University of Bonn, Bonn, Germany; 2011.
88. FAO (Food and Agriculture Organization). Micronutrients. FAO, Fertilizer and Plant Nutrition Bulletin 7. Rome, Italy; 1983.

89. Mandal B, Hazra GC, Mandal LN. Soil management influence on zinc desorption for rice and maize nutrition. Soil Science Society of America Journal. 2000;64:1699–1705.
90. Chinnery LE, Harding CP. The effect of ferrous iron on the uptake of manganese by *Juncus effusus*. Journals of Botany. 1980;46: 409–412.
91. Goldberg S, Glaubig RA. Boron adsorption on California soils. Soil Science Society of America Journal. 1986;50:1173-1176.
92. Moraghan JT, Mascagni HJ. Environmental and soil factors affecting micronutrient deficiencies and toxicities. In: Micronutrients in agriculture. Soil Science Society of America. Madison, WI, U.S.A. 1991;371-425.
93. Swietlik D. Interaction between zinc deficiency and boron toxicity on growth and mineral nutrition of sour orange seedlings. Journal of Plant Nutrition. 1995;18:1191–1207.
94. Follett RH, Murphy LS, Donahue RL. Fertilizers and soil amendments. Englewood Cliffs, New Jersey: Prentice-Hall; 1981.
95. Aref F. Concentration of zinc and boron in corn leaf as affected by zinc sulfate and boric acid fertilizers in a deficient soil. Life Science Journal. 2011;8(1):2–11.